

This Page Is Inserted by IFW Operations  
and is not a part of the Official Record

## **BEST AVAILABLE IMAGES**

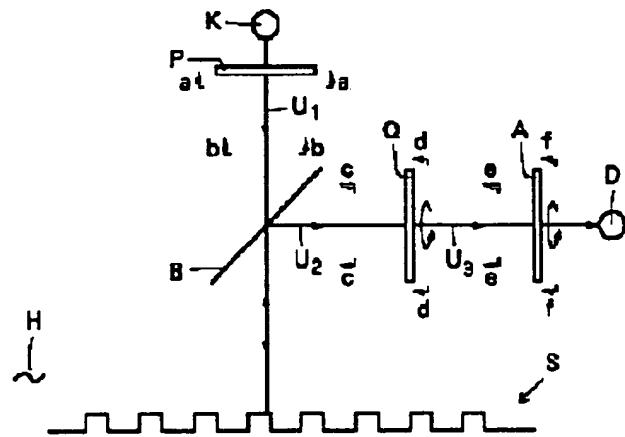
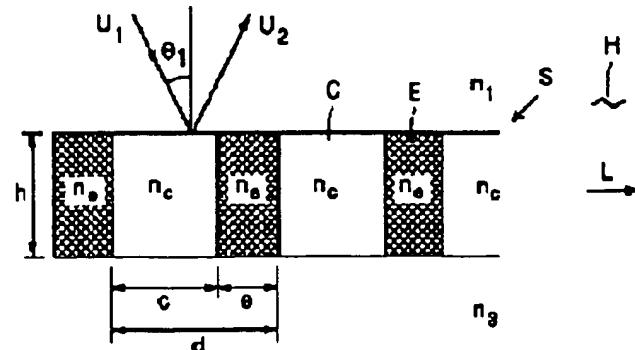
Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images may include (but are not limited to):

- BLACK BORDERS
- TEXT CUT OFF AT TOP, BOTTOM OR SIDES
- FADED TEXT
- ILLEGIBLE TEXT
- SKEWED/SLANTED IMAGES
- COLORED PHOTOS
- BLACK OR VERY BLACK AND WHITE DARK PHOTOS
- GRAY SCALE DOCUMENTS

**IMAGES ARE BEST AVAILABLE COPY.**

**As rescanning documents *will not* correct images,  
please do not report the images to the  
Image Problems Mailbox.**



**JP11211421**  
**DEVICE AND METHOD FOR MEASURING LINE WIDTH**  
**NIKON CORP**  
**Inventor(s): ; ITO YOSHINOBU**  
**Application No. 10030600, Filed 19980127, Published 19990806**

**Abstract:** PROBLEM TO BE SOLVED: To provide a device and method for measuring a line width in which the line width of a fine line-and-space pattern having a periodic structure can be easily measured.

**SOLUTION:** In a line width measuring device for measuring a line width (e) of respective lines of a line-and-space pattern S having a plurality of lines arranged at a fixed pitch (d) in a fixed direction L, a polarized light U<sub>1</sub> is incident on the pattern S, and the polarized state of the reflected light U<sub>2</sub> from the pattern S is measured, whereby the change amount of polarized state of the polarized light U<sub>1</sub> caused in the reflection by the pattern S is measured, and the line width (e) is measured on the basis of the change amount of polarized state.

**Int'l Class:** G01B01102;

**MicroPatent Reference Number:** 000211362

**COPYRIGHT:** (C) 1999JPO

(19)日本国特許庁 (JP)

(12) 公開特許公報 (A)

(11)特許出願公開番号

特開平11-211421

(43)公開日 平成11年(1999)8月6日

(51)Int.Cl.  
G 0 1 B 11/02

識別記号

F I  
G 0 1 B 11/02

Z

審査請求 未請求 請求項の数10 FD (全 10 頁)

(21)出願番号 特願平10-30600

(22)出願日 平成10年(1998)1月27日

(71)出願人 000004112

株式会社ニコン

東京都千代田区丸の内3丁目2番3号

(72)発明者 伊藤 良延

東京都千代田区丸の内3丁目2番3号 株式会社ニコン内

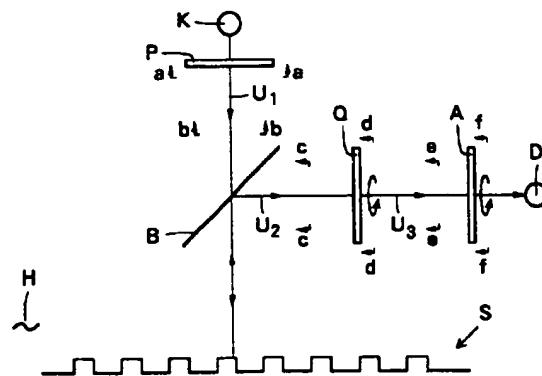
(74)代理人 弁理士 猪熊 克彦

(54)【発明の名称】 線幅測定装置及び方法

(57)【要約】

【課題】周期構造を持つ微細なラインアンドスペースパターンの線幅を容易に測定することができる線幅測定装置及び方法を提供する。

【解決手段】一定の方向に一定のピッチdにて複数本の線を配置したラインアンドスペースパターンSの各々の線の線幅eを測定する線幅測定装置において、パターンSに偏光光U<sub>1</sub>を入射し、パターンSからの反射光U<sub>2</sub>の偏光状態を測定することによって、パターンSで反射する際に生じる偏光光U<sub>1</sub>の偏光状態の変化量を測定し、偏光状態の変化量に基づいて、線幅eを測定することを特徴とする。



## 【特許請求の範囲】

【請求項1】一定の方向に一定のピッチにて複数本の線を配置したラインアンドスペースパターンの前記各々の線の線幅を測定する線幅測定装置において、前記パターンに偏光光を入射し、前記パターンからの反射光の偏光状態を測定することによって、前記パターンで反射する際に生じる前記偏光光の偏光状態の変化量を測定し、該偏光状態の変化量に基づいて、前記線幅を測定することを特徴とする線幅測定装置。

【請求項2】前記パターンに入射する入射光は、前記各々の線と直交する線直交平面に対して、平行に入射することを特徴とする請求項1記載の線幅測定装置。

【請求項3】前記入射光の光路に偏光子を配置して、前記パターンに直線偏光を入射することを特徴とする請求項2記載の線幅測定装置。

【請求項4】前記反射光の光路に、光軸周りに回転可能な1/4波長板と、光軸周りに回転可能な検光子とをその順に配置し、前記検光子を透過する光束の消光状態における前記1/4波長板の中性軸の方位、若しくは前記検光子の透過軸の方位、又はその双方に基づいて、前記偏光状態の変化量を測定することを特徴とする請求項3記載の線幅測定装置。

【請求項5】前記反射光の光路に、光軸周りに回転不能な1/4波長板と、光軸周りに回転可能な検光子とをその順に配置し、前記検光子を透過する光束の光量が最大又は最小となる状態における前記検光子の透過軸の方位に基づいて、前記偏光状態の変化量を測定することを特徴とする請求項3記載の線幅測定装置。

【請求項6】前記反射光の光路に、光軸周りに回転可能な1/4波長板と、光軸周りに回転不能な検光子とをその順に配置し、前記検光子を透過する光束の光量が最大又は最小となる状態における前記1/4波長板の中性軸の方位に基づいて、前記偏光状態の変化量を測定することを特徴とする請求項3記載の線幅測定装置。

【請求項7】前記反射光の光路に、光軸周りに回転不能な検光子を配置したことを特徴とする請求項2記載の線幅測定装置。

【請求項8】前記入射光の光路に、偏光子と1/4波長板とをその順に配置し、該偏光子と1/4波長板とのうちの少なくともいずれか一方を光軸周りに回転可能に配置し、前記検光子を透過する光量が最大又は最小となる状態における前記回転自在に配置した部材の透過軸又は中性軸の方位に基づいて、前記偏光状態の変化量を測定することを特徴とする請求項7記載の線幅測定装置。

【請求項9】前記入射光の光路に偏光子を配置し、反射

光の光路に検光子を配置し、

前記偏光子と検光子のうちの一方を光軸周りに回転不能に配置し、他方を光軸周りに回転可能に配置し、前記検光子を透過する光束の光量が最大又は最小となる状態における前記回転可能に配置した部材の透過軸の方位に基づいて、前記偏光状態の変化量を測定することを特徴とする請求項3記載の線幅測定装置。

【請求項10】一定の方向に一定のピッチにて複数本の線を配置したラインアンドスペースパターンの前記各々の線の線幅を測定する線幅測定方法において、

前記パターンとして線幅の既知な較正用パターンを用意し、該較正用パターンに偏光光を入射し、較正用パターンからの反射光の偏光状態を測定することによって、較正用パターンで反射する際に生じる前記偏光光の偏光状態の変化量を測定し、該偏光状態の変化量と前記線幅との関係を求める較正工程と、

前記パターンとして線幅の未知な測定用パターンを用意し、該測定用パターンに偏光光を入射し、測定用パターンからの反射光の偏光状態を測定することによって、測定用パターンで反射する際に生じる前記偏光光の偏光状態の変化量を測定し、該偏光状態の変化量と前記関係によって、前記未知の線幅を求める測定工程と、を有することを特徴とする線幅測定方法。

## 【発明の詳細な説明】

## 【0001】

【発明の属する技術分野】本発明は、半導体露光装置などで焼き付けられる周期構造をもつレジスト像の線幅や、レジスト像をマスクにしてエッチング法にて基板上に形成される周期構造をもつエッチング像の線幅を、偏光解析法により測定する線幅測定装置及び方法に関するものである。

## 【0002】

【従来の技術】半導体製造プロセスにおいては、種々の露光条件やエッチング条件で作成された膨大な数のサンプルについて、レジスト像やエッチング像の線幅を計測することにより、最適な露光条件やエッチング条件を定めている。線幅を測定する手法としては、従来より、顕微鏡画像を処理してレジスト像やエッチング像の線幅を計測する方法や、レジスト像やエッチング像のエッジからの散乱光を利用して線幅を計測する方法などが用いられてきた。しかるに近年、光源の短波長化と光学系のNA（開口数）の増大に伴い、シリコンウエハ上に形成される微細パターンの線幅は年を追うごとに微細化してきている。この結果、線幅が0.25μmを切る最先端のプロセス技術では、顕微鏡画像を処理して線幅を計測する方法や、エッジからの散乱光を利用して線幅を計測する方法では、最早用をななくなつて来ている。そこで電子顕微鏡を用いてレジスト像やエッチング像を観察して、その線幅を測定する手法が用いられつつある。

【発明が解決しようとする課題】しかしながら、電子顕微鏡による観察、測定では、試料を適当な大きさに切断しなければならないこと、真空容器内に試料を装填しなければならないこと、などにより、時間と手間を要する作業となっている。したがって試料の切断などを行うことなく非破壊で、且つ試料を真空容器などに装填することなくそのままの状態で線幅を測定することができる手法が確立されれば、フォトリソグラフィーやエッチングなどのための最適条件の決定に要する時間と手間が、大幅に短縮されることになる。そこで本発明は、周期構造を持つ微細なラインアンドスペースパターンの線幅を容易に測定することができる線幅測定装置及び方法を提供することを課題とする。

## 【0004】

【課題を解決するための手段】本発明は上記課題を解決するためになされたものであり、すなわち、一定の方向に一定のピッチにて複数本の線を配置したラインアンドスペースパターンの前記各々の線の線幅を測定する線幅測定装置において、前記パターンに偏光光を入射し、前記パターンからの反射光の偏光状態を測定することによって、前記パターンで反射する際に生じる前記偏光光の偏光状態の変化量を測定し、該偏光状態の変化量に基づいて、前記線幅を測定することを特徴とする線幅測定装置である。本発明はまた、一定の方向に一定のピッチにて複数本の線を配置したラインアンドスペースパターンの前記各々の線の線幅を測定する線幅測定方法において、前記パターンとして線幅の既知な較正用パターンを用意し、該較正用パターンに偏光光を入射し、較正用パターンからの反射光の偏光状態を測定することによって、較正用パターンで反射する際に生じる前記偏光光の偏光状態の変化量を測定し、該偏光状態の変化量と前記関係とによって、前記未

$$N_e^2 = (c/d)n_c^2 + (e/d)n_e^2$$

$$N_e^2 = \frac{n_c^2 n_e^2}{(c/d)n_e^2 + (e/d)n_c^2}$$

【0008】上記(1a)式と(1b)式との比較より明らかのように、2つの媒質の屈折率 $n_c$ 、 $n_e$ のいかんに拘わらず常に $(N_e)^2 < (N_c)^2$ が成立するので、この構造性複屈折体は負の一軸性光学結晶と等価になる。構成物質によって違いはあるが、上記近似式が成立するためには、格子周期に対する光の波長の比 $\lambda/d$ が、 $\lambda/d > 40$ である必要があると言われている(C W Haggans et al. 1982; C W Haggans et al. 1993)。

\* 知の線幅を求める測定工程と、を有することを特徴とする線幅測定方法である。

【0005】以下に本発明の原理について説明する。ラインアンドスペースパターンS、すなわち周期性構造体の断面図を図1に示す。同図において、

$U_1$  : パターンSへの入射光

$U_2$  : パターンSからの反射光

$\theta_1$  : 入射光の入射角

$n_1$  : 入射光側の媒質の屈折率

10  $n_c$  : パターンSを構成する第1媒質Cの屈折率

$n_e$  : パターンSを構成する第2媒質Eの屈折率

$n_3$  : パターンSの基板を構成する媒質の屈折率

$d$  : パターンSの周期 ( $d \equiv c + e$ )

$c$  : 第1媒質Cの幅

$e$  : 第2媒質Eの幅

$h$  : 第1媒質Cと第2媒質Eの高さ

である。第1媒質Cと第2媒質Eは、例えば第1媒質がレジストであり、第2媒質がレジストに形成された潜像であっても良いし、また、第1媒質が空間、すなわち入射光側の媒質と同じ媒質であり、第2媒質がレジストであっても良い。

【0006】ここで入射光は、第1媒質又は第2媒質の長手方向と直交する線直交平面(すなわち、回折光子の格子面の法線と格子ベクトルとして作られる平面)Hに対して平行に入射するものとする。図1では、線直交平面Hは紙面と一致している。また、電場ベクトルが線直交平面Hと垂直な偏光をs偏光と呼び、電場ベクトルが線直交平面Hと平行な偏光をp偏光と呼ぶ。

【0007】図1に示すような屈折率の異なる2つ物質C、Eが交互に並んだ周期性構造体は、複屈折性を有することが古くから知られており、「構造性複屈折(form birefringence)」と呼ばれている。特に格子周期dが波長入に較べて格段に短い周期性構造体では、s偏光、p偏光に対する等価屈折率 $N_s$ 、 $N_p$ は各々次のように表されることが知られている(M Born and E Wolf: Principles of Optics, Pergamon Press, 1959, 702-705)。

(1a)

(1b)

※1.: J Opt Soc Am, vol. 10, No. 10, 2217-2225, 1993)。波長入に較べて格子周期dが充分に短いとは言えない周期性構造体においても複屈折の現象は見られるが、最近まで定量的な解析は行なわれていなかった。しかるに最近、波長に較べて格子周期が充分に短いとは言えない周期性構造体における等価屈折率 $N_s$ 、 $N_p$ を求める簡便な方法(EMT法)が確立された(R C MacPhedran et al. 1982; C W Haggans et al. 1982; C W Haggans et al. 1993)。

et al.: J Opt Soc Am, vol. 10, No. 10, 2217-2225. 1993).

$$N_o^2 = \frac{\mu_s^2 + \alpha_0^2}{k_o^2}$$

$$N_e^2 = \frac{\mu_p^2}{k_o^2 [1 - (\sin \theta_1)^2 / N_o^2]}$$

但し、 $\alpha_0 = k_o \sin \theta_1$

$$k_o = 2\pi / \lambda$$

$\lambda$  : 入射側媒質中の光の波長

$\mu_s$  : s 偏光に対する格子内固有モードを決定する固有値方程式の最大根

$\mu_p$  : p 偏光に対する格子内固有モードを決定する固有値方程式の最大根

である。  $d \rightarrow 0$  の極限において (2a)、(2b) 式は (1a)、(1b) 式に一致することは当然であるが、回折格子を構成する材料が誘電体である場合に限って言えば、(2a)、(2b) 式は、格子周期  $d$  が波長  $\lambda$  と同程度までのかなり広い範囲でよい近似法であることが分かっている。

【0010】図2に、EMT法に基づいて計算した等価屈折率差曲線（等価屈折率差  $N_o - N_e$  と、第2媒質Eのデューティー比  $e/d$  との関係を表した曲線）を、種々の波長入に対して計算した結果を示す。計算に用いた回折格子の屈折率は、

$$n_c = 1.0, n_e = 1.5, \theta_1 = 0^\circ$$

としている。図から明らかなように、第2媒質のデューティー比  $e/d$  が小さいときには、屈折率差  $N_o - N_e$  は極くわずかであるが、デューティー比  $e/d$  が増すに従って屈折率差  $N_o - N_e$  は増加する。そして  $\lambda > 3d$  程度の場合には、 $e/d = 0.5 \sim 0.6$  で極大に達する。その後デューティー比  $e/d$  が増すに従って屈折率差  $N_o - N_e$  は減少を始め、第2媒質が格子全体を覆い尽くすようになると屈折率差は再び0に近づく。図では  $\lambda > 5d$  の場合については図示していないが、 $\lambda > 5d$  のとき※

$$r_s = \frac{r_{12}^s + r_{23}^s \exp(2i\beta_s)}{1 + r_{12}^s r_{23}^s \exp(2i\beta_s)}$$

但し、

$$r_{12}^s = \frac{n_1 \cos \theta_1 - N_o \cos \theta_2}{n_1 \cos \theta_1 + N_o \cos \theta_2}, \quad r_{23}^s = \frac{N_o \cos \theta_2 - n_3 \cos \theta_3}{N_o \cos \theta_2 + n_3 \cos \theta_3}$$

$$\beta_s = \left( \frac{2\pi}{\lambda} \right) N_o h \cos \theta_2$$

である。

【0013】p 偏光の場合には、図3における薄膜の屈折率  $n_2$  を等価屈折率  $N_e$  に等しいと置いて、反射係数  $r_p$  は次のように表される。

$$r_p = \frac{r_{12}^p + r_{23}^p \exp(2i\beta_p)}{1 + r_{12}^p r_{23}^p \exp(2i\beta_p)}$$

\* 【0009】このEMT法によれば、s 偏光、p 偏光に対する等価屈折率  $N_o$ 、 $N_e$  は次式で与えられる。

(2a)

(2b)

※には、 $\lambda = 5d$  の場合と殆ど同じであり、すなわち  $\lambda = 10d$  程度で飽和する。逆に波長入が短くなると、等価屈折率差  $N_o - N_e$  が最大になる位置が図中左側（第2媒質のデューティー比  $e/d$  が少ない側）に移動し、且つわずかではあるが屈折率差  $N_o - N_e$  が大きくなっていく。等価屈折率差曲線のこのような波長依存性を利用することにより、第2媒質のデューティー比  $e/d$  を精度良く知ることができる。そして一般に格子の周期  $d$  は既知であるから、こうして線幅  $e$  を精度良く測定できることとなる。

【0011】さて、被測定物となるラインアンドスペースパターンSは、s 偏光に対する等価屈折率が  $N_o$  であり、p 偏光に対する等価屈折率が  $N_e$  である一軸性光学結晶と等価である。したがって反射係数  $r_s$ 、 $r_p$  は、s 偏光の場合には屈折率が  $N_o$  である薄膜の反射係数と同じになり、p 偏光の場合には屈折率が  $N_e$  である薄膜の反射係数と同じになる。図3に、薄膜の反射係数を求めるための諸量の定義を示す。同図に示すように、

$n_2$  : 薄膜の屈折率

$\theta_2$  : 薄膜内を通過する光線の角度

$\theta_3$  : 薄膜から射出する光線の角度

とする。その他の  $n_1$ 、 $n_3$ 、 $\theta_1$ 、 $h$  の意味は、図1のときと同じである。

【0012】以上のように定義すると、s 偏光の場合には、図3における薄膜の屈折率  $n_2$  を等価屈折率  $N_o$  に等しいと置いて、反射係数  $r_s$  は次のように表される (M B ornard E Wolf: Principles of Optics, Pergamon Press, 1959, 60-65)。

(3)

★屈折率  $n_2$  を等価屈折率  $N_e$  に等しいと置いて、反射係数  $r_p$  は次のように表される。

(4)

但し、 $\delta_s$ ：基準状態に対する s 偏光の位相  
 $\delta_p$ ：基準状態に対する p 偏光の位相  
 である。

【0019】この反射光の偏光状態は、図6(c)に示すように、一般には橢円偏光であり、その主軸の方位 $\psi$ と、橢円の長軸と短軸の比  $\tan 2\chi$  は、各々次式より求められる (M Born and E Wolf: Principles of Optics, Pergamon Press, 1959, 24-27)。

$$\tan 2\psi = (\tan 2\alpha) \cos \delta$$

$$\tan 2\chi = (\sin 2\alpha) \sin \delta$$

$$U_2 = \begin{pmatrix} a \\ ib \end{pmatrix}$$

但し、

$$a = \sqrt{|r_p|^2 + |r_s|^2} \cos \chi$$

$$b = \sqrt{|r_p|^2 + |r_s|^2} \sin \chi$$

$$Q = \begin{pmatrix} 1 & 0 \\ 0 & -i \end{pmatrix}$$

したがって図6(e)に示すように、 $1/4$ 波長板Qを通過後の光 $U_3$ の偏光状態は、(8)、(9)式を用い ★

$$U_3 = Q U_2 = \begin{pmatrix} a \\ b \end{pmatrix}$$

【0022】これはX-Y座標系において、 $\chi = \tan^{-1}(b/a)$  方向に振動する直線偏光であることを意味している。したがって図6(f)に示すように、検光子Aの透過軸A $\chi$ の方位を $\psi + \chi \pm \pi/2$ に設定すれば、検光子Aを通過する光量は0となり、消光状態が実現できる。消光状態を実現するために回転すべき $1/4$ 波長板Qと検光子Aの回転角より、それぞれ橢円偏光の主軸の方位 $\psi$ と橢円率 $\tan 2\chi$ とを知ることができ、すなわち反射光の偏光状態 $U_2$ を知ることができる。他方、入射光の偏光状態 $U_1$ は既知であるから、両偏光状態 $U_1$ 、 $U_2$ から、ラインアンドスペースパターンSの偏光特性を知ることができ、すなわちパターンSの反射係数 $r_s$ 、 $r_p$ を知ることができ、この結果、パターンSの第2媒質のデューティー比 $e/d$ が求められることとなる。

【0023】図7に、さまざまなデューティー比 $e/d$ に対して、 $\psi$ と $\chi$ を計算した結果を示す。計算条件は、 $\lambda = 2d$ 、 $h = 0.1d$ 、 $\theta_1 = 0^\circ$

$$n_1 = n_c = 1.0, n_e = n_3 = 1.5$$

としている。曲線の右端の白丸が $e/d = 2\%$ に対応し、左端の白丸が $e/d = 9.8\%$ に対応し、連続する白丸は2%キザミとなっている。

【0024】線幅測定においては、まず最初に図7に示すような $\psi$ と $\chi$ とデューティー比 $e/d$ との間の関係を表す検量線を作成する。回折格子の断面形状が単純な場合には、ここで述べたEMT法を用いて検量線を作成する☆50

\* 但し、

$$\tan \alpha = |r_p| / |r_s|$$

$$\delta = \delta_p - \delta_s$$

である。

【0020】この橢円の主軸方向 $\psi$ にX軸を一致させたX-Y座標系で偏光状態を表すこととすれば、反射光の偏光状態 $U_2$ は(8)式のように表される。

※である。

【0021】他方、図6(d)に示すように、進相軸Q $x$ をX軸(すなわち主軸方位 $\psi$ )に合わせた $1/4$ 波長板Qのジョーンズ行列は、X-Y座標系で(9)式のように表される。

★で(10)式のように表される。

☆ことができる。しかし、より複雑な断面形状をもつ場合には、既に線幅の分かっているサンプルを用いて、図4又は図5に示す偏光解析装置で実験的に検量線を作成してもよい。しかる後に、線幅が未知のサンプルに対して図4又は図5に示す偏光解析装置を用いて、消光状態における $1/4$ 波長板の中性軸(進相軸又は遅相軸)の回転角 $\psi$ と、検光子の透過軸の回転角 $\psi + \chi \pm \pi/2$ を測定する。最後に、線幅が未知のサンプルに対する測定値 $\psi$ 、 $\chi$ より、既に作成した検量線を用いてデューティー比 $e/d$ を求める。一般に格子のピッチ $d$ は既知であるから、こうして線幅 $e$ を求めることができる。なお、検量線は数値の形で保管してもよいし、数式の形で保管してもよい。

30 30

【0025】図7より明らかなように、 $\psi$ と $\chi$ は、デューティー比 $e/d$ を知るためにリダンダントとなっている。したがって $\psi$ と $\chi$ の両方を知れば、デューティー比 $e/d$ の測定精度は当然に上昇するものの、 $\psi$ と $\chi$ のどちらか一方だけからデューティー比 $e/d$ を求めることもできる。図8に、 $1/4$ 波長板Qの回転角 $\psi$ からデューティー比 $e/d$ を求めるための検量線を示す。計算条件は、図7の場合と同じである。なお、 $\psi$ と $e/d$ との関係をプロットした図8の検量線では、同一の $\psi$ に対して2つの $e/d$ が存在する場合があり、したがって検量線の極大値、又は極小値付近で $e/d$ の精度が低下する。これに対して $\chi$ と $e/d$ との関係をプロットした検量線を用いれば、図7より明らかなように、同一の $\chi$

11

に対して2つの $e/d$ が存在することはなくなる。なお明らかに、検量線の勾配が最も急な場所に、想定される $e/d$ の値が来るような検量線を用いることが好ましい。

【0026】また、 $\Psi$ と $\chi$ は、デューティー比 $e/d$ を知るためにリダンダントであるから、例えば検量線として、 $\Psi + \chi$ 、すなわち、検光子の透過軸と直交する方向（消光軸）の方位と、デューティー比 $e/d$ との関係を表したもの用いることもできる。図9に、 $\Psi + \chi$ からデューティー比 $e/d$ を求めるための検量線を示す。

計算条件は、

$$\lambda = 4 \text{ d}, h = 0, 1 \text{ d}, \theta_1 = 0^\circ$$

$$n_1 = n_2 = 1, 0, n_e = n_3 = 1, 5$$

としている。図8又は図9に示す検量線を用いる場合も、線幅が既知のサンプルを用いて検量線を作成し、その検量線を用いて測定しようとするラインアンドスペースパターンの線幅を測定することが好ましい。

【0027】次に第2実施例について説明する。楕円偏光の偏光状態は、（楕円偏光の回転方向を除いて）2つのパラメータ $\Psi, \chi$ で決定される。上記第1実施例では、 $1/4$ 波長板Qと検光子Aとを共に光軸周りに回転自在に配置して消光状態を実現することにより、上記2つのパラメータ $\Psi, \chi$ を双方とも求め得る構成とした。しかし既述のごとく、デューティー比 $e/d$ を知るためにには、2つのパラメータ $\Psi, \chi$ を共に知る必要はなく、楕円偏光の偏光状態を決定する何らか1つのパラメータさえ分かれば良い。そこでこの第2実施例では、 $1/4$ 波長板Qを適切な角度（一般的にはデューティー比が $e/d = 0, 5$ で消光状態が達成される角度）に固定し、検光子Aのみが回転する構成としている。すなわち $1/4$ 波長板Qが固定されている点を除いて、図4又は図5と同じであるから、この第2実施例の図示は省略する。そして検光子Aを回転させ、透過光量（すなわち検出器Dの出力）が最大（あるいは最小）となる検光子Aの回転角度より、デューティー比 $e/d$ を求める。図10には、さまざまな $e/d$ に対して、透過光量が最大となる検光子の回転角 $\theta$ を計算した結果を示す。計算条件は、 $\lambda = 2 \text{ d}$ （図10（a））、 $\lambda = 3 \text{ d}$ （図10（b）） $h = 0, 1 \text{ d}, \theta_1 = 0^\circ$

$$n_1 = n_e = 1, 0, n_e = n_3 = 1, 5$$

としている。

【0028】次に第3実施例について説明する。この第3実施例では、検光子Aを適切な角度（一般的にはデューティー比が $e/d = 0, 5$ で消光状態が達成される角度）に固定し、 $1/4$ 波長板Qのみが回転する構成としている。すなわち検光子Aが固定されている点を除いて、図4又は図5と同じであるから、この第3実施例の図示は省略する。そして $1/4$ 波長板Qを回転させ、透過光量（すなわち検出器Dの出力）が最大（あるいは最小）となる $1/4$ 波長板Qの回転角度より、デューティー比 $e/d$ を求める。図10には、さまざまな $e/d$ に対して、透過光量が最大となる検光子の回転角 $\theta$ を計算した結果を示す。計算条件は、 $\lambda = 2 \text{ d}$ （図10（a））、 $\lambda = 3 \text{ d}$ （図10（b）） $h = 0, 1 \text{ d}, \theta_1 = 0^\circ$

$$n_1 = n_e = 1, 0, n_e = n_3 = 1, 5$$

としている。

【0029】次に第4実施例について説明する。既述のように、デューティー比 $e/d$ を知るためにには、楕円偏光の偏光状態を決定する何らか1つのパラメータさえ分かれば良い。したがってラインアンドスペースパターンSより反射された光 $U_2$ が直線偏光に近い場合には、 $1/4$ 波長板Wを省略することができ、光軸周りに回転可能な検光子Aのみを設ける構成とすることができる。そして検光子Aを回転させ、透過光量が最大（あるいは最小）となる検光子の回転角度より、デューティー比 $e/d$ を求める。なお、図10の（a）と（b）に見られるように、図7～図10に示す全ての検量線は波長依存性をもっている。精度よく線幅を測定するためには、デューティー比 $e/d$ の変化に対して、検量線が適切な大きさで変化する波長を選択することが肝要である。

10

【0030】以上の各実施例においては、偏光子Pの透過軸 $P_x$ の方位は、図6（a）に示すように、線直交平面Hに対して $45^\circ$ の方向に設定されており、したがってラインアンドスペースパターンSへの入射光 $U_1$ は、図6（b）に示すように、s成分とp成分の複素振幅の等しい直線偏光となっていた。しかしパターンSの反射係数 $r_s, r_p$ を知るためにには、入射光の偏光状態 $U_1$ と反射光の偏光状態 $U_2$ が分かれれば良い。したがって偏光子Pの透過軸 $P_x$ の線直交平面Hに対する角度は、必ずしも $45^\circ$ である必要はない。更に、入射光は必ずしも直線偏光である必要もないから、必ずしも偏光子Pを配置する必要もない。

20

【0031】また、上記各実施例においては、入射光 $U_1$ の偏光状態を一定として、反射光の偏光状態を測定していた。しかしながら入射光の偏光状態 $U_1$ を可変とすることもできる。すなわち図11は第5実施例を示し、光源Kからの光束を偏光子Pと $1/4$ 波長板Qとを介してラインアンドスペースパターンSに入射し、パターンSからの反射光を検光子Aを介して光検出器Dに入射させている。そして偏光子Pと $1/4$ 波長板Qとはそれぞれ光軸周りに回転可能に配置し、検出器Dにおいて消光状態が実現される状態の偏光子Pと $1/4$ 波長板Qの回転角度を測定する。この構成によっても、パターンSでの反射に際して付与される偏光状態の変化量を測定することができる。

30

【0032】また、パターンSでの反射に際して付与される偏光状態の変化量のうち、何らか1つのパラメータさえ分かれば良いのであるから、偏光子Pを固定して $1/4$ 波長板Qのみを回転自在とし、あるいはその逆に、偏光子Pのみを回転自在として $1/4$ 波長板Qを固定することもできる。また、偏光子Pと $1/4$ 波長板Qを一体として回転自在とすることもできるし、 $1/4$ 波長板Qを削除して偏光子Pを回転自在とすることもできる。

40

50

12

【0033】次に第6実施例について説明する。既述のように、デューティー比 $e/d$ を知るためにには、楕円偏光の偏光状態を決定する何らか1つのパラメータさえ分かれば良い。したがってラインアンドスペースパターンSより反射された光 $U_2$ が直線偏光に近い場合には、 $1/4$ 波長板Wを省略することができ、光軸周りに回転可能な検光子Aのみを設ける構成とすることができる。そして検光子Aを回転させ、透過光量が最大（あるいは最小）となる検光子の回転角度より、デューティー比 $e/d$ を求める。なお、図10の（a）と（b）に見られるように、図7～図10に示す全ての検量線は波長依存性をもっている。精度よく線幅を測定するためには、デューティー比 $e/d$ の変化に対して、検量線が適切な大きさで変化する波長を選択することが肝要である。

【0034】以上の各実施例においては、偏光子Pの透過軸 $P_x$ の方位は、図6（a）に示すように、線直交平面Hに対して $45^\circ$ の方向に設定されており、したがってラインアンドスペースパターンSへの入射光 $U_1$ は、図6（b）に示すように、s成分とp成分の複素振幅の等しい直線偏光となっていた。しかしパターンSの反射係数 $r_s, r_p$ を知るためにには、入射光の偏光状態 $U_1$ と反射光の偏光状態 $U_2$ が分かれれば良い。したがって偏光子Pの透過軸 $P_x$ の線直交平面Hに対する角度は、必ずしも $45^\circ$ である必要はない。更に、入射光は必ずしも直線偏光である必要もないから、必ずしも偏光子Pを配置する必要もない。

【0033】これまでの計算例においては、回折格子は誘電体から出来ていると仮定してきたが、半導体集積回路においては、誘電体に限らず金属を含めた各種の薄膜が使われている。これらの薄膜からなる周期性構造体においても、s偏光に対する固有値方程式とp偏光に対する固有値方程式は元来異なるものであるから、各々の固有値方程式から得られる最大根（この最大根によって等価屈折率が決定される）は異なるのが一般的である。これより、薄膜材料の如何に拘わらず周期性構造体には常に複屈折性が存在し、その等価屈折率は線幅依存性を持つこととなる。

【0034】更に、これまでの計算例においては、図1に示すような矩形の断面形状をもつ回折格子を仮定してきた。しかしながら、半導体リソグラフィー技術を用いて作成される周期性構造体では、このような矩形の断面形状をもつことは稀である。このような状況下では、等価屈折率は（2a）、（2b）式のような単純な形では表現できない。このような場合であっても、構造に周期性がある場合には必ず構造性複屈折が存在し、その等価屈折率は線幅依存性を持つこととなる。これらの議論より、周期性構造体の材料、断面形状の如何に拘わらず、ここで述べた偏光解析法を適用することにより、線幅測定が可能となることが分かる。

### 【0035】

【発明の効果】以上のように本発明による線幅測定装置及び方法によれば、測定の前準備として、各種測定量と線幅を関係づける検量線を作成する作業が必要となるが、一旦検量線が出来てしまえば、実際の測定は試料を破壊することなく、しかも大気中で出来るので、手間の掛かっている線幅測定の時間が大幅に短縮されることと

10

なる。

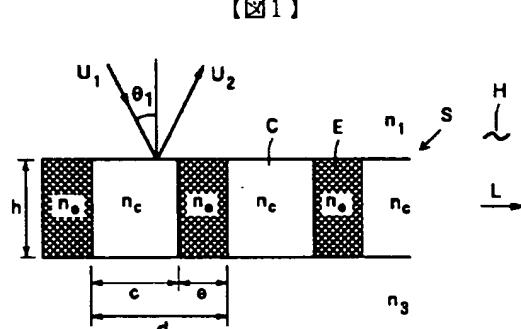
【図面の簡単な説明】  
 【図1】ラインアンドスペースパターンを示す縦断面図  
 【図2】等価屈折率差のデューティー比と波長に対する依存性を示す説明図  
 【図3】ラインアンドスペースパターンと等価な薄膜を示す断面図  
 【図4】第1実施例による線幅測定装置を示す構成図  
 【図5】第1実施例の別の態様を示す構成図  
 【図6】図4及び図5中、a-a線～f-f線矢規図  
 【図7】ラインアンドスペースパターンからの反射光の偏光特性のデューティー比に対する依存性を示す図  
 【図8】消光状態における検光子の消光軸の方位のデューティー比に対する依存性を示す図  
 【図9】消光状態における1/4波長板の進相軸の方位のデューティー比に対する依存性を示す図  
 【図10】透過光量が最大となる状態における検光子の透過軸の方位のデューティー比に対する依存性を示す図  
 【図11】第5実施例による線幅測定装置を示す構成図

20

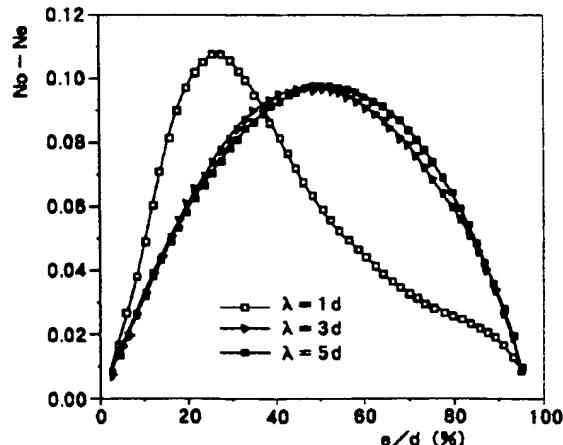
### 【符号の説明】

K…光源	P…偏光子
P x…透過軸	B…ビームスプリッタ
ター	
U <sub>1</sub> …入射光	S…ラインアンドス
ベースパターン	
U <sub>2</sub> …反射光	ペース
Q x…進相軸	Q…1/4波長板
A x…透過軸	A…検光子
H…線直交平面	D…光検出器

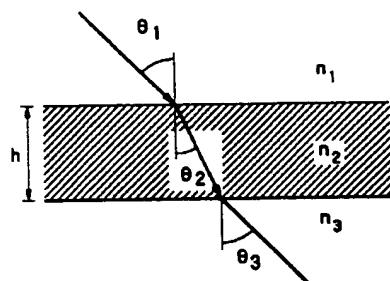
30



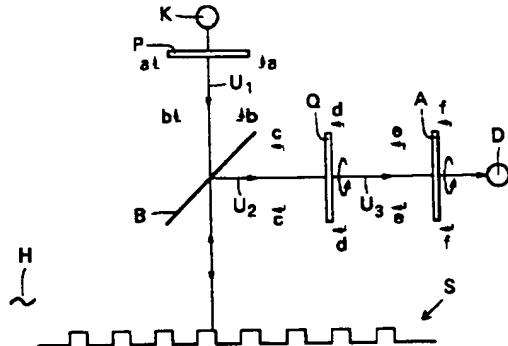
【図2】



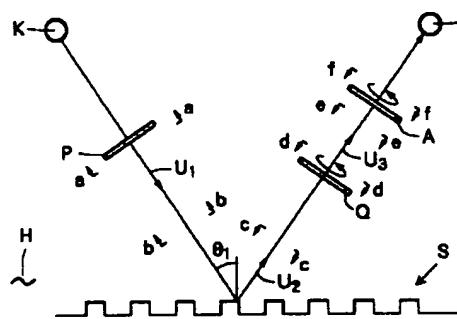
【図3】



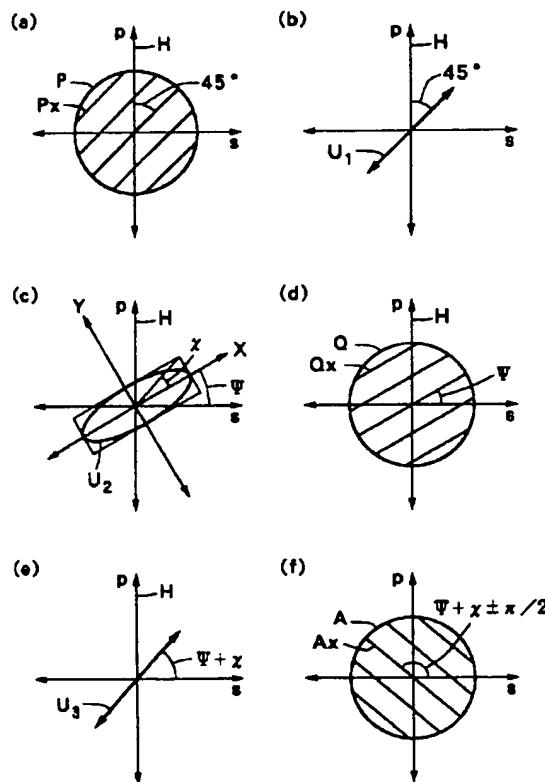
【図4】



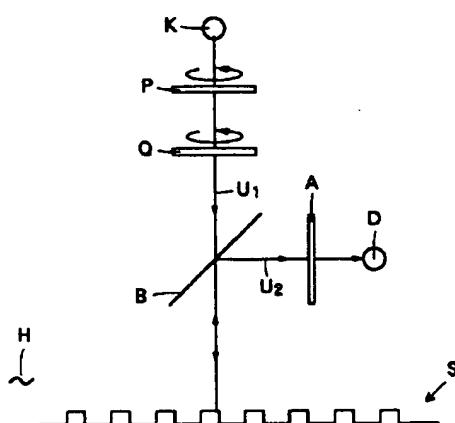
【図5】



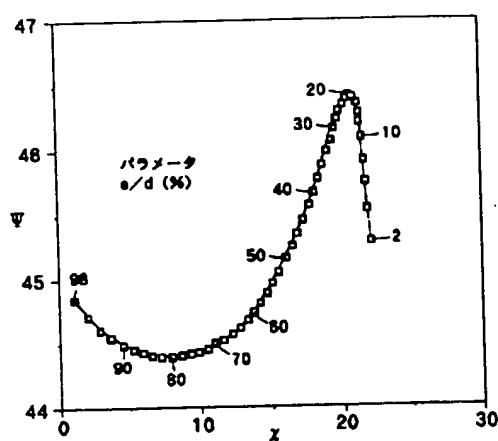
【図6】



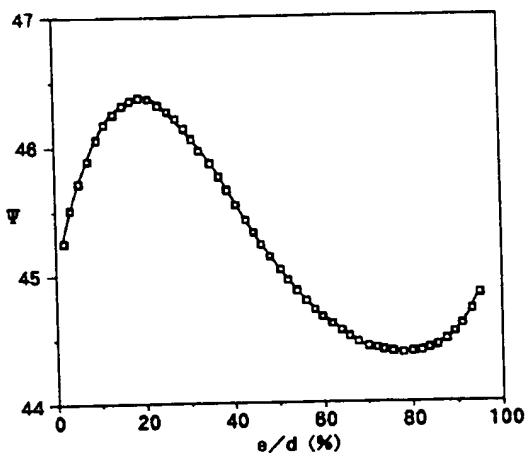
【図11】



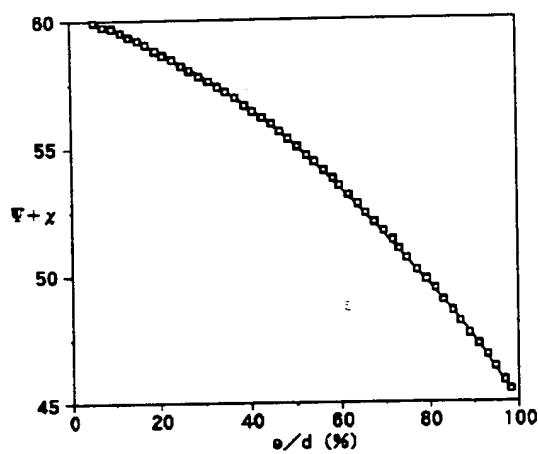
【図7】



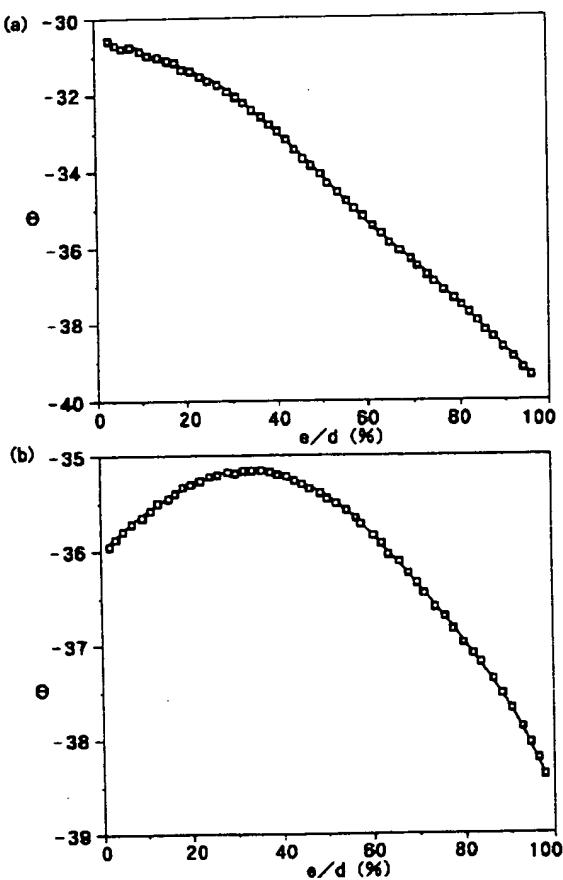
【図8】



【図9】



【図10】



# PATENT ABSTRACTS OF JAPAN

(11)Publication number : 11-211421

(43)Date of publication of application : 06.08.1999

(51)Int.Cl.

G01B 11/02

(21)Application number : 10-030600

(71)Applicant : NIKON CORP

(22)Date of filing : 27.01.1998

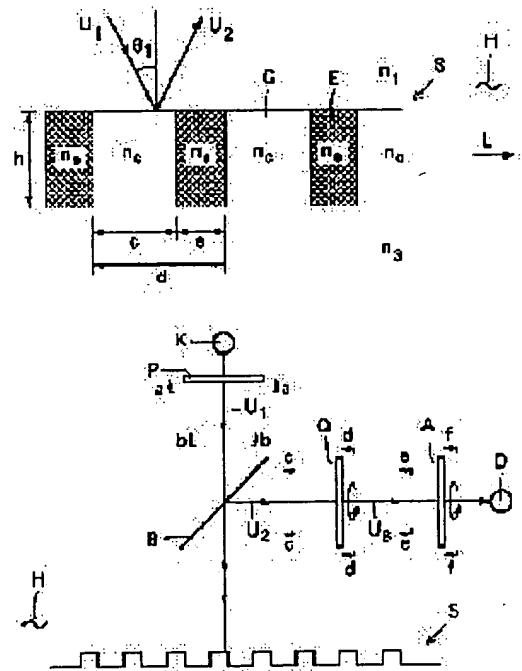
(72)Inventor : ITO YOSHINOBU

## (54) DEVICE AND METHOD FOR MEASURING LINE WIDTH

### (57)Abstract:

**PROBLEM TO BE SOLVED:** To provide a device and method for measuring a line width in which the line width of a fine line-and-space pattern having a periodic structure can be easily measured.

**SOLUTION:** In a line width measuring device for measuring a line width (e) of respective lines of a line-and-space pattern S having a plurality of lines arranged at a fixed pitch (d) in a fixed direction L, a polarized light U1 is incident on the pattern S, and the polarized state of the reflected light U2 from the pattern S is measured, whereby the change amount of polarized state of the polarized light U1 caused in the reflection by the pattern S is measured, and the line width (e) is measured on the basis of the change amount of polarized state.



## LEGAL STATUS

[Date of request for examination]

[Date of sending the examiner's decision of rejection]

[Kind of final disposal of application other than the examiner's decision of rejection or application converted registration]

[Date of final disposal for application]

[Patent number]

[Date of registration]

[Number of appeal against examiner's decision of rejection]

[Date of extinction of right]

Copyright (C); 1998,2000 Japan Patent Office

\* NOTICES \*

Japan Patent Office is not responsible for any damages caused by the use of this translation.

1. This document has been translated by computer. So the translation may not reflect the original precisely.
2. \*\*\*\* shows the word which can not be translated.
3. In the drawings, any words are not translated.

---

## CLAIMS

---

### [Claim(s)]

[Claim 1] In the line breadth measuring device which measures the line breadth of the line of each above of the line which has arranged two or more lines in the fixed pitch in the fixed orientation, and a space pattern The line breadth measuring device which carries out incidence of the polarization light to the aforementioned pattern, and is characterized by measuring the variation of the polarization status of the aforementioned polarization light produced in case it reflects by the aforementioned pattern by measuring the polarization status of the reflected light from the aforementioned pattern, and measuring the aforementioned line breadth based on the variation of this polarization status.

[Claim 2] the line breadth measuring device according to claim 1 characterized by carrying out incidence of the incident light which carries out incidence to the aforementioned pattern in parallel to the line rectangular cross flat surface which intersects perpendicularly with the line of each above

[Claim 3] The line breadth measuring device according to claim 2 characterized by arranging a polarizer to the optical path of the aforementioned incident light, and carrying out incidence of the linearly polarized light to the aforementioned pattern.

[Claim 4] The line breadth measuring device according to claim 3 characterized by measuring the variation of the aforementioned polarization status based on the azimuth of the neutral shaft of the 1/4 aforementioned wavelength plate in the quenching status of the flux of light which arranges 1/4 wavelength plate which can rotate to the circumference of an optical axis, and the analyzer which can rotate to the circumference of an optical axis in the order, and penetrates the aforementioned analyzer to the optical path of the aforementioned reflected light, the azimuth of the transparency shaft of the aforementioned analyzer, or its both sides.

[Claim 5] The line breadth measuring device according to claim 3 characterized by measuring the variation of the aforementioned polarization status based on the azimuth of the transparency shaft of the aforementioned analyzer in the status that the quantity of light of the flux of light which arranges 1/4 wavelength plate which cannot be rotated, and the analyzer which can rotate to the circumference of an optical axis in the order, and penetrates the aforementioned analyzer to the circumference of an optical axis at the optical path of the aforementioned reflected light serves as the maximum or the minimum.

[Claim 6] The line breadth measuring device according to claim 3 characterized by measuring the variation of the aforementioned polarization status to the optical path of the aforementioned reflected light based on the azimuth of the neutral shaft of the 1/4 aforementioned wavelength plate in the status that the quantity of light of the flux of light which arranges 1/4 wavelength plate which can rotate to the circumference of an optical axis, and the analyzer which cannot be rotated to the circumference of an optical axis in the order, and penetrates the aforementioned analyzer serves as the maximum or the minimum.

[Claim 7] The line breadth measuring device according to claim 2 characterized by having arranged the analyzer which cannot be rotated to the circumference of an optical axis to the optical path of the aforementioned reflected light.

[Claim 8] To the optical path of the aforementioned incident light, arrange a polarizer and 1/4 wavelength plate at the order, and inside [ this polarizer and 1/4 wavelength plate ] arranges any or one side possible [ rotation ] to the circumference of an optical axis at least. The line breadth measuring device according to claim 7 characterized by the quantity of light which penetrates the aforementioned analyzer measuring the variation of the aforementioned polarization status based on the azimuth of the transparency shaft of the member arranged free [ the aforementioned rotation in the status become the maximum or the minimum ], or a neutral shaft.

[Claim 9] Arrange a polarizer to the optical path of the aforementioned incident light, and an analyzer is arranged to the optical path of the reflected light. Arrange one of the aforementioned polarizer and the analyzers to the circumference of an optical axis at the rotation impotentia, and another side is arranged possible [ rotation ] to the circumference of an

optical axis. The line breadth measuring device according to claim 3 characterized by the quantity of light of the flux of light which penetrates the aforementioned analyzer measuring the variation of the aforementioned polarization status based on the azimuth of the transparency shaft of the member arranged possible [ the aforementioned rotation in the status become the maximum or the minimum ].

[Claim 10] In the line breadth measuring method which measures the line breadth of the line of each above of the line which has arranged two or more lines in the fixed pitch in the fixed orientation, and a space pattern By preparing the known line breadth pattern for calibration, carrying out incidence of the polarization light to this pattern for calibration, and measuring the polarization status of the reflected light from the pattern for calibration as the aforementioned pattern The calibration process which measures the variation of the polarization status of the aforementioned polarization light produced in case it reflects by the pattern for calibration, and asks for the relation between the variation of this polarization status, and the aforementioned line breadth, By preparing the strange pattern for measurement of line breadth, carrying out incidence of the polarization light to this pattern for measurement, and measuring the polarization status of the reflected light from the pattern for measurement as the aforementioned pattern The line breadth measuring method characterized by having the measurement process which measures the variation of the polarization status of the aforementioned polarization light produced in case it reflects by the pattern for measurement, and asks for the line breadth of the aforementioned strangeness by the variation and the aforementioned relation of this polarization status.

---

[Translation done.]

\* NOTICES \*

Japan Patent Office is not responsible for any damages caused by the use of this translation.

1. This document has been translated by computer. So the translation may not reflect the original precisely.

2. \*\*\*\* shows the word which can not be translated.

3. In the drawings, any words are not translated.

---

## DETAILED DESCRIPTION

---

### [Detailed Description of the Invention]

[0001]

[The technical field to which invention belongs] this invention relates to the line breadth measuring device and technique of measuring the line breadth of the resist image with the periodic structure printed by the semiconductor aligner etc., and the line breadth of the etching image with the periodic structure which uses a resist image as a mask and is formed on a substrate by the etching method by the polarization analysis.

[0002]

[Description of the Prior Art] In the semiconductor manufacture process, the optimum exposure conditions and etching conditions are defined by measuring the line breadth of a resist image or an etching image about a huge number of samples created on various exposure conditions and etching conditions. The technique of measuring line breadth using the scattered light from the edge of technique, a resist image, or an etching image which processes a microscope picture image and measures the line breadth of a resist image or an etching image conventionally as the technique of measuring line breadth etc. has been used. However, whenever the line breadth of the detailed pattern formed on a silicon wafer in connection with short-wavelength-izing of the light source and increase of NA (numerical aperture) of optical system follows a year, it has been made detailed in recent years. Consequently, with the latest process technique of cutting 0.25 micrometers, in the technique of processing a microscope picture image and measuring line breadth, and the technique of measuring line breadth using the scattered light from an edge, line breadth does not make business any longer and has become. Then, a resist image and an etching image are observed using an electron microscope, and the technique of measuring the line breadth is used.

[0003]

[Problem(s) to be Solved by the Invention] However, in observation by the electron microscope, and measurement, it is the work which requires time and time that a sample must be cut in a suitable size, by having to load with a sample into a vacuum housing, etc. Therefore, if the technique of the ability to measure line breadth in the status as it is is established, without not destroying, without performing a disconnection of a sample etc. and loading a vacuum housing etc. with a sample, the time and time which the decision of the optimum conditions for photo lithography, etching, etc. takes will be shortened sharply. Then, this invention makes it a technical problem to offer the line breadth measuring device and technique of measuring easily the line breadth of the detailed line and space pattern with periodic structure.

[0004]

[Means for Solving the Problem] In the line breadth measuring device which measures the line breadth of the line of each above of the line which is made in order that this invention may solve the above-mentioned technical problem, namely, has arranged two or more lines in the fixed pitch in the fixed orientation, and a space pattern By carrying out incidence of the polarization light to the aforementioned pattern, and measuring the polarization status of the reflected light from the aforementioned pattern It is the line breadth measuring device characterized by measuring the variation of the polarization status of the aforementioned polarization light produced in case it reflects by the aforementioned pattern, and measuring the aforementioned line breadth based on the variation of this polarization status. In the line breadth measuring method with which this invention measures again the line breadth of the line of each above of the line which has arranged two or more lines in the pitch fixed in fixed orientation, and a space pattern By preparing the known line breadth pattern for calibration, carrying out incidence of the polarization light to this pattern for calibration, and measuring the polarization status of the reflected light from the pattern for calibration as the aforementioned pattern The calibration process which measures the variation of the polarization status of the aforementioned polarization light produced in case it reflects by the pattern for calibration, and asks for the relation between the variation of this polarization status, and the aforementioned line breadth, By preparing the strange pattern for measurement of line breadth, carrying out incidence of the polarization light to this pattern for measurement, and

measuring the polarization status of the reflected light from the pattern for measurement as the aforementioned pattern It is the line breadth measuring method characterized by having the measurement process which measures the variation of the polarization status of the aforementioned polarization light produced in case it reflects by the pattern for measurement, and asks for the line breadth of the aforementioned strangeness by the variation and the aforementioned relation of this polarization status.

[0005] The principle of this invention is explained below. The cross section of a line and space pattern S, i.e., the periodicity structure, is shown in drawing 1. The period of refractive-index d:pattern S of the medium which constitutes the substrate of refractive-index n3:pattern S of the 2nd medium E which constitutes refractive-index ne:pattern S of 1st medium C which constitutes refractive-index nc:pattern S of the medium by the side of the incident angle n1:incident light of the reflected light theta1:incident light from incident-light U2:pattern S to U1:pattern S in this drawing (d\*\*c+e)

c: It is the height of width-of-face h:1st medium C of the width-of-face e:2nd medium E of 1st medium C, and the 2nd medium E. For example, the 1st medium may be a resist, and 1st medium C and the 2nd medium E may be the latent images by which the 2nd medium was formed in the resist, and the 1st medium may be a medium by the side of space, i.e., an incident light, and the same medium, and the 2nd medium may be a resist.

[0006] Incidence of the incident light shall be carried out in parallel here to line rectangular cross flat-surface (namely, flat surface made from normal and grid vector L of lattice plane of diffraction photon) H which intersects perpendicularly with the longitudinal direction of the 1st medium or the 2nd medium. Line rectangular cross flat-surface H is in agreement with space in drawing 1. Moreover, an electric field vector calls polarization perpendicular to line rectangular cross flat-surface H s-polarized light, and calls the polarization with an electric field vector parallel to line rectangular cross flat-surface H p-polarized light.

[0007] Having birefringence nature is known for many years, and the periodicity structure with which the two matter C and E with which a refractive index which is shown in drawing 1 is different was located in a line by turns is called "constitutive-property birefringence (form birefringence)." especially the effective refractive indexs [ as opposed to / grid period d is markedly alike compared with wavelength lambda, and / an s-polarized light and a p-polarized light at the short periodicity structure ] No and Ne -- each -- what is expressed as follows is known (M Born and E Wolf: Principles of Optics, Pergamon Press, 1959, 702-705)

$$N_o^2 = (c/d)n_c^2 + (e/d)n_e^2 \quad (1a)$$

$$N_e^2 = \frac{n_c^2 n_e^2}{(c/d)n_e^2 + (e/d)n_c^2} \quad (1b)$$

[0008] Since (Ne)<sup>2</sup><(No)<sup>2</sup> are always materialized irrespective of the situation of the refractive indexes nc and ne of two media so that more clearly than the comparison with the above-mentioned (1a) formula and a formula (1b), this constitutive-property birefringence field becomes negative optically uniaxial optical crystal and negative equivalence. the ratio of the wavelength of light [ as opposed to / although there is a difference with a constituent, in order to materialize the above-mentioned approximation / a grid period ] -- lambda/d is said that it is necessary to be lambda / d>40 (C W Haggans et al.: vol. 10, No. J Opt Soc Am, 10, 2217- 2225, 1993) Although the phenomenon of a birefringence was seen also in the periodicity structure which grid period d cannot say is short enough compared with wavelength lambda, analysis quantitive to recently was not performed. However, the effective refractive index No in the periodicity structure which a grid period cannot say recently is short enough compared with wavelength, Ne The simple technique (the EMT method) of searching for was established ( ). [ R ] C MacPhedran et al.: Oct Acta, vol.26, and No.3,289- 312 and 1982; C W Haggans et al.: J Opt Soc Am, vol.10, No.10, and 2217- 2225 and 1993

[0009] According to this EMT method, the effective refractive indexs No and Ne to an s-polarized light and a p-polarized light are given by the following formula.

$$N_o^2 = \frac{\mu_s^2 + \alpha_o^2}{k_o^2} \quad (2a)$$

$$N_e^2 = \frac{\mu_p^2}{k_o^2 [1 - (\sin \theta_1)^2 / N_o^2]} \quad (2b)$$

however, alpha0=k0sintheta -- it is the maximum solution of the characteristic value equation which determines the native mode in a grid over the maximum solution muP:p-polarized light of a characteristic value equation which

determines the native mode in a grid over the wavelength mus:s-polarized light of the light in a 0=2pi/lambda:incidence side medium 1 k In the limit of d>0 (2a), although a formula (2b) is naturally in agreement with (1 a) and a formula (1b), if it says only within the case where the material which constitutes a diffraction grating is a dielectric, it turns out that (2a) and a formula (2b) are the approximations with grid period d sufficient in the quite large domain of wavelength lambda and until of the same grade.

[0010] The result which calculated the effective-refractive-index difference curve (curve showing the relation between effective-refractive-index difference No-Ne and the duty ratio e/d of the 2nd medium E) calculated based on the EMT method to various wavelength lambda is shown in drawing 2. The refractive index of the diffraction grating used for the calculation is made into nc=1.0, ne=1.5, and theta1=0 degree. clear from drawing -- as -- the duty ratio e/d of the 2nd medium -- the time of the parvus -- refractive-index difference No-Ne -- \*\*\*\* -- although it is small, duty ratio e/d increases -- it is alike, and it follows and refractive-index difference No-Ne increases And in about [ lambda>3d ], it reaches by e/d=0.5-0.6 at the maximum. If refractive-index difference No-Ne begins a decrement and the 2nd medium comes to cover the whole grid as duty ratio e/d increases after that, a refractive-index difference will approach 0 again. Although not illustrated about a lambda> 5d case drawing, at the lambda> 5d time, it is almost the same as that of a lambda= 5d case, namely, is saturated with about [ lambda=5d ] at it. Conversely, if wavelength lambda becomes short, the position where effective-refractive-index difference No-Ne becomes the maximum moves to the left-hand side in drawing (side with little duty ratio e/d of the 2nd medium), and although it is small, refractive-index difference No-Ne becomes large. By using such a wavelength dependency of an effective-refractive-index difference curve, the duty ratio e/d of the 2nd medium can be known with a sufficient precision. And generally, since periodic d of a grid is known, in this way, it can measure line breadth e with a sufficient precision.

[0011] Now, the effective refractive index to an s-polarized light is No, and the line and space pattern S used as a device under test have the equivalent effective refractive index to a p-polarized light to the optically uniaxial optical crystal which is Ne. Therefore, in the case of an s-polarized light, reflection coefficients rs and rP become the same as that of the reflection coefficient of the thin film whose refractive index is No, and in being a p-polarized light, a refractive index becomes the same as that of the reflection coefficient of the thin film which is Ne. A definition of the amount of many for asking for the reflection coefficient of a thin film is shown in drawing 3. As shown in this drawing, it considers as the angle of the beam of light injected from the angle theta3:thin film of a beam of light which passes through the inside of the refractive-index theta2:thin film of an n2:thin film. The meaning of n1 and n3 of theta 1, and h is the same as that of the time of drawing 1.

[0012] When a definition is given as mentioned above, in the case of an s-polarized light, the refractive index n2 of the thin film in drawing 3 will be placed if equal to an effective refractive index No, and a reflection coefficient rs is expressed to it as follows (M Born and E Wolf: Principles of Optics, Pergamon Press, 1959, 60-65).

$$r_s = \frac{r_{12}^s + r_{23}^s \exp(2i\beta_s)}{1 + r_{12}^s r_{23}^s \exp(2i\beta_s)} \quad (3)$$

$$r_{12}^s = \frac{n_1 \cos \theta_1 - N_o \cos \theta_2}{n_1 \cos \theta_1 + N_o \cos \theta_2}, \quad r_{23}^s = \frac{N_o \cos \theta_2 - n_3 \cos \theta_3}{N_o \cos \theta_2 + n_3 \cos \theta_3}$$

$$\text{however } \beta_s = \left(\frac{2\pi}{\lambda}\right) N_o h \cos \theta_2$$

It comes out.

[0013] In the case of a p-polarized light, the refractive index n2 of the thin film in drawing 3 will be placed if equal to an effective refractive index Ne, and a reflection coefficient rP is expressed to it as follows.

$$r_p = \frac{r_{12}^p + r_{23}^p \exp(2i\beta_p)}{1 + r_{12}^p r_{23}^p \exp(2i\beta_p)} \quad (4)$$

$$r_{12}^p = \frac{N_e \cos \theta_1 - n_1 \cos \theta_2}{N_e \cos \theta_1 + n_1 \cos \theta_2}, \quad r_{23}^p = \frac{n_3 \cos \theta_2 - N_e \cos \theta_3}{n_3 \cos \theta_2 + N_e \cos \theta_3}$$

$$\text{however } \beta_p = \left(\frac{2\pi}{\lambda}\right) N_e h \cos \theta_2$$

It comes out.

[0014] As mentioned above, when the duty ratio e/d of the 2nd medium E of a line and space pattern S changes, the

effective refractive indexes  $N_o$  and  $N_e$  of pattern S will change, and, as a result, the reflection coefficients  $r_s$  and  $r_p$  of pattern S will change. That is, reflection coefficients  $r_s$  and  $r_p$  will be influenced of the duty ratio  $e/d$  of line breadth through effective refractive indexes  $N_o$  and  $N_e$ . And change of reflection coefficients  $r_s$  and  $r_p$  changes the variation of the polarization status given in case of the reflex by the line and space pattern S. Therefore, by knowing the polarization status of an incident light and the reflected light, the variation of the polarization status of the polarization light produced in case it reflects by pattern S can be known, and duty ratio  $e/d$  can be known from this variation.

[0015]

[Embodiments of the Invention] The gestalt of operation of this invention is explained. Drawing 4 and the drawing 5 show the 1st example of the line breadth measuring device by this invention. In the mode shown in drawing 4, in order to set the incident angle  $\theta_1$  of an incident light  $U_1$  to  $\theta_1=0$ , therefore to separate an incident light  $U_1$  and the reflected light  $U_2$ , beam-splitter B is used. On the other hand, in the mode shown in drawing 5, the incident angle  $\theta_1$  of an incident light  $U_1$  is set to  $\theta_1 \neq 0$ , therefore beam-splitter B is not used. Other content is the same in both modes. The light from light source K penetrates polarizer P, and it is carrying out incidence to a line and space pattern S. As light source K, what emits long wave length  $\lambda$  a little is used rather than pitch  $d$  of pattern S, of the same grade, or pitch  $d$ , therefore this pattern S serves as the "zero-order diffraction grating" which diffracted light except zero-order does not generate. Moreover, the orientation of the flux of light which carries out incidence to pattern S is orientation parallel to line rectangular cross flat-surface H (flat surface parallel to space) which intersects perpendicularly with each line of pattern S. Moreover, as the azimuth of the transparency shaft  $P_x$  of polarizer P is shown in drawing 6 (a), it is set up in the 45-degree orientation to line rectangular cross flat-surface H, therefore the incident light  $U_1$  to pattern S is the linearly polarized light with the equal complex amplitude of s component and p component, as shown in drawing 6 (b). Henceforth, the angle within an s-p flat surface is carried out on the basis of the orientation of s.

[0016] After the reflected light  $U_2$  from a line and space pattern S penetrates  $1/4$  wavelength-plate Q arranged free [ the rotation to the circumference of an optical axis ], and analyzer A arranged it is the same and free [ the rotation to the circumference of an optical axis ] in the order, incidence of it is carried out to light-sensitive-cell D. Although the zero-order diffracted light reflected from pattern S generally turns into an elliptically polarized light as shown in drawing 6 (c), it is asked for the main shaft azimuth  $\psi$  and ovality  $tanchi$  as follows. That is, the output of light-sensitive-cell D is measured, rotating  $1/4$  wavelength-plate Q, and analyzer A, the quenching status that the output of light-sensitive-cell D is set to 0 is realized, and it is asked for main shaft azimuth  $\psi$  and ovality  $tanchi$  of the reflected light from angle-of-rotation  $\psi + \chi \cdot \pi/2$  of the transparency shaft  $A_x$  of angle-of-rotation  $\psi$  of the neutral shaft  $Q_x$  of  $1/4$  wavelength plate at this time, and an analyzer. Since main shaft azimuth  $\psi$  and ovality  $tanchi$  of this reflected light change according to the duty ratio  $e/d$  of the 2nd medium E of pattern S, the duty ratio  $e/d$  of the 2nd medium will be calculated by asking for the main shaft azimuth and ovality of the reflected light. Hereafter, suppose that a Jones vector is used and the polarization status is expressed for quantification.

[0017] Although the incident light  $U_1$  which carries out incidence to a line and space pattern S is the linearly polarized light to which 45 degrees of electric field vectors inclined to line rectangular cross flat-surface H, this is expressed like a formula (5) using a Jones vector.

$$U_1 = \begin{pmatrix} 1 \\ 1 \end{pmatrix} \quad (5)$$

Moreover, the polarization property of pattern S is expressed like a formula (6) using a Jones matrix.

$$S = \begin{pmatrix} r_s & 0 \\ 0 & r_p \end{pmatrix} \quad (6)$$

However, it is the reflection coefficient of the line to  $r_s$ :s-polarized light, the line to the reflection coefficient  $r_p$ :p-polarized light of space pattern S, and space pattern S.

[0018] The polarization status  $U_2$  of light reflected from a line and space pattern S becomes like a formula (7) from (5) and (6) formulas.

$$U_2 = S U_1 = \begin{pmatrix} r_s \\ r_p \end{pmatrix} = \begin{pmatrix} |r_s| e^{i\delta_s} \\ |r_p| e^{i\delta_p} \end{pmatrix} \quad (7)$$

However, it is the phase of the p-polarized light to the phase  $\delta_p$ :reference state of the s-polarized light to a  $\delta_s$ :reference state.

[0019] the polarization status of this reflected light is shown in drawing 6 (c) -- as -- general -- an elliptically polarized

light -- it is -- the ratio of azimuth psi of the main shaft, the major axis of an ellipse, and a minor axis -- it is asked for tanchi from an each degree type (M Born and E Wolf: Principles of Optics, Pergamon Press, 1959, 24-27)

•  $\tan 2\Psi = (\tan 2\alpha) \cos \delta$

$\tan 2\chi = (\sin 2\alpha) \sin \delta$

$$\tan \alpha = |r_p| / |r_s|$$

however  $\delta = \delta_p - \delta_s$

It comes out.

[0020] The thing for which the polarization status is expressed with X-Y coordinate system which made the X-axis in agreement with orientation [ of a main shaft ] psi of this ellipse, then the polarization status U2 of the reflected light are expressed like (8) formulas.

$$U_2 = \begin{pmatrix} a \\ ib \end{pmatrix} \quad (8)$$

$$a = \sqrt{|r_p|^2 + |r_s|^2} \cos \chi$$

however  $b = \sqrt{|r_p|^2 + |r_s|^2} \sin \chi$

It comes out.

[0021] On the other hand, as shown in drawing 6 (d), the Jones matrix of 1 / 4 wavelength-plate Q which set the phase leading shaft Qx by the X-axis (namely, main shaft azimuth psi) is expressed with X-Y coordinate system like (9) formulas.

$$Q = \begin{pmatrix} 1 & 0 \\ 0 & -i \end{pmatrix} \quad (9)$$

Therefore, as shown in drawing 6 (e), the polarization status of the light U3 after passing 1 / 4 wavelength-plate Q is expressed like (10) formulas using (8) and (9) formulas.

$$U_3 = QU_2 = \begin{pmatrix} a \\ b \end{pmatrix} \quad (10)$$

[0022] It means that this is linearly polarized light which vibrates in the  $\chi = \tan^{-1}(b/a)$  orientation in X-Y coordinate system. Therefore, if the azimuth of the transparency shaft Ax of analyzer A is set as  $\psi + \chi \cdot \pi/2$  as shown in drawing 6 (f), the quantity of light which passes analyzer A is set to 0, and can realize the quenching status. From the angle of rotation of 1 / 4 wavelength-plate Q which should rotate in order to realize the quenching status, and analyzer A, azimuth psi and ovality tanchi of a main shaft of an elliptically polarized light can be known, respectively, namely, the polarization status U2 of the reflected light can be known. On the other hand, since the polarization status U1 of an incident light is known, from both the polarization status U1 and U2, the polarization property of a line and space pattern S can be known, namely, the reflection coefficients rs and rP of pattern S can be known, and, as a result, it will be asked for the duty ratio e/d of the 2nd medium of pattern S.

[0023] The result which calculated psi and chi is shown in drawing 7 to various duty ratio e/d. Calculation conditions are set to  $\lambda = 2d$ ,  $h = 0.1d$ ,  $\theta = 0$  degrees,  $n_c = 1.0$ , and  $n_e = n_3 = 1.5$ . The white round head at the right end of curved corresponds to  $e/d = 2\%$ , and the white round head with which a left end white round head corresponds and continues to  $e/d = 98\%$  serves as \*\*\*\*\* 2%.

[0024] Line breadth measurement \*\*\*\*\* creates the calibration curve showing the relation between psi, chi, and the duty ratio e/d which are first shown in drawing 7. When the cross-section configuration of a diffraction grating is simple, a calibration curve can be created using the EMT method described here. However, when it has a more complicated cross-section configuration, you may already create a calibration curve experimentally using the \*\*\*\*\* sample of line breadth with the polarization analysis equipment shown in the drawing 4 or the drawing 5. After an appropriate time, line breadth measures angle-of-rotation  $\psi + \chi \cdot \pi/2$  of angle-of-rotation psi of the neutral shaft (a phase leading shaft or lagging axis) of 1/4 wavelength plate in the quenching status, and the transparency shaft of an analyzer using the polarization analysis equipment shown in the drawing 4 or the drawing 5 to a strange sample. Line breadth asks the last for duty ratio e/d from measured-value psi to a strange sample, and chi using the already created calibration curve. Generally, since pitch d of a grid is known, in this way, it can calculate line breadth e. In addition, a calibration curve may be saved in numerical type and may be saved in the type of a formula.

[0025] In order to know duty ratio e/d, psi and chi are \*\*\*\*\* so that more clearly than drawing 7. Therefore, if

both psi and chi are known, although the accuracy of measurement of duty ratio e/d naturally goes up, it can also ask for duty ratio e/d only from one of psi and chi. The calibration curve for asking for duty ratio e/d from angle-of-rotation [ of 1 / 4 wavelength-plate Q ] psi is shown in drawing 8 . Calculation conditions are the same as that of the case of drawing 7 . In addition, in the calibration curve of the drawing 8 which plotted the relation between psi and e/d, two e/d may exist to the same psi, therefore the precision of e/d falls a maximal value or near a minimal value a calibration curve. On the other hand, if the calibration curve which plotted the relation between chi and e/d is used, it will be lost that two e/d exists to the same chi so that more clearly than drawing 7 . In addition, it is desirable to use a calibration curve by which the value of e/d assumed comes to the location where the inclination of a calibration curve is the steepest clearly.

[0026] Moreover, since psi and chi are \*\*\*\*\*'s in order to know duty ratio e/d, the thing showing the azimuth of the orientation (quenching shaft) which intersects perpendicularly with psi+chi, i.e., the transparency shaft of an analyzer, and the relation with duty ratio e/d can also be used for them, for example as a calibration curve. The calibration curve for asking for duty ratio e/d from psi+chi is shown in drawing 9 . Calculation conditions are set to  $\lambda=4d$ ,  $h=0.1d$ ,  $\theta=0^\circ$ ,  $n=1.0$ , and  $n_e=1.5$ . When using the calibration curve shown in the drawing 8 or the drawing 9 , it is desirable to measure the line breadth of the line which line breadth tends to create a calibration curve using a known sample, and tends to measure using the calibration curve, and a space pattern.

[0027] Next, the 2nd example is explained. The polarization status of an elliptically polarized light is determined by two (removing hand of cut of elliptically polarized light) parameters psi, and chi. In the 1st above-mentioned example, it considered as the configuration which can ask for two above-mentioned parameters psi and chi also with both sides by arranging 1 / 4 wavelength-plate Q, and analyzer A free [ both rotations to the circumference of an optical axis ], and realizing the quenching status. However, in order [ both ] to know duty ratio e/d like previous statement, it is not necessary to know two parameters psi and chi, and even what or one parameter which determines the polarization status of an elliptically polarized light should just be known. Then, in this 2nd example, 1 / 4 wavelength-plate Q is fixed to a suitable angle (angle from which the quenching status is generally attained for duty ratio by  $e/d=0.5$ ), and it is considering as the configuration which only analyzer A rotates. That is, except for the point that 1 / 4 wavelength-plate Q is being fixed, since it is the same as that of the drawing 4 or the drawing 5 , illustration of this 2nd example is omitted. And analyzer A is rotated and it asks for duty ratio e/d from angle of rotation of analyzer A from which the amount (namely, output of detector D) of transmitted lights serves as the maximum (or minimum). The result which calculated angle-of-rotation theta of the analyzer with which the amount of transmitted lights serves as the maximum is shown in drawing 10 to e/Various d. Calculation conditions are  $\lambda=2d$  ( drawing 10 (a) ) and  $\lambda=3d$  ( drawing 10 (b) ).

It is referred to as  $h=0.1d$ ,  $\theta=0^\circ$ ,  $n=1.0$ , and  $n_e=1.5$ .

[0028] Next, the 3rd example is explained. In this 3rd example, analyzer A is fixed to a suitable angle (angle from which the quenching status is generally attained for duty ratio by  $e/d=0.5$ ), and it is considering as the configuration which only 1 / 4 wavelength-plate Q rotates. That is, except for the point that analyzer A is being fixed, since it is the same as that of the drawing 4 or the drawing 5 , illustration of this 3rd example is omitted. And 1 / 4 wavelength-plate Q is rotated, and it asks for duty ratio e/d from angle of rotation of 1 / 4 wavelength-plate Q from which the amount (namely, output of detector D) of transmitted lights serves as the maximum (or minimum). In addition, it is good as another example also as a configuration which rotates 1 / 4 wavelength-plate Q, and analyzer A as one.

[0029] Next, the 4th example is explained. Like previous statement, in order to know duty ratio e/d, even what or one parameter which determines the polarization status of an elliptically polarized light should just be known. Therefore, when the light U2 reflected from a line and space pattern S is close to the linearly polarized light, 1 / 4 wavelength-plate W can be omitted, and it can consider as the configuration which prepares only analyzer A which can rotate to the circumference of an optical axis. And analyzer A is rotated and it asks for duty ratio e/d from angle of rotation of the analyzer with which the amount of transmitted lights serves as the maximum (or minimum). In addition, all the calibration curves shown in drawing 7 - view 10 have a wavelength dependency so that (b) may regard as (a) of drawing 10 . In order to measure line breadth with a sufficient precision, it is important that a calibration curve chooses the wavelength which changes in a suitable size to change of duty ratio e/d.

[0030] In each above example, as the azimuth of the transparency shaft Px of polarizer P was shown in drawing 6 (a) , it is set up in the 45-degree orientation to line rectangular cross flat-surface H, therefore the incident light U1 to a line and space pattern S had turned into the linearly polarized light with the equal complex amplitude of s component and p component, as shown in drawing 6 (b) . However, in order to know the reflection coefficients  $r_s$  and  $r_p$  of pattern S, the polarization status U1 of an incident light and the polarization status U2 of the reflected light should just carry out understanding. Therefore, the angle to line rectangular cross flat-surface H of the transparency shaft Px of polarizer P does not necessarily need to be 45 degrees. Furthermore, since an incident light does not necessarily need to be the

linearly polarized light, it does not necessarily need to arrange polarizer P.

[0031] Moreover, the polarization status of the reflected light was measured in each above-mentioned example, having set the polarization status of an incident light U1 as constant. However, the polarization status U1 of an incident light can also be made adjustable. That is, drawing 11 shows the 5th example, carries out incidence of the flux of light from light source K to a line and space pattern S through polarizer P, and 1 / 4 wavelength-plate Q, and carries out incidence of the reflected light from pattern S to light-sensitive-cell D through analyzer A. And polarizer P, and 1 / 4 wavelength-plate Q arrange possible [ the rotation to the circumference of an optical axis ], respectively, and angle of rotation of polarizer P of the status that the quenching status is realized in detector D, and 1 / 4 wavelength-plate Q is measured. The variation of the polarization status given in case of the reflex by pattern S by this configuration can be measured.

[0032] Moreover, since even one parameter should just be known to some extent among the variations of the polarization status given in case of the reflex by pattern S, polarizer P can be fixed, and rotation of only 1 / 4 wavelength-plate Q can be enabled, or rotation of only polarizer P can be enabled at the reverse, and 1 / 4 wavelength-plate Q can also be fixed. Moreover, rotation can also be made free, being able to use polarizer P, and 1 / 4 wavelength-plate Q as one, 1 / 4 wavelength-plate Q can be deleted, and rotation of polarizer P can also be enabled.

[0033] In the old example of a calculation, although it assumes that the diffraction grating is made of a dielectric, in the semiconductor integrated circuit, various kinds of thin films not only including a dielectric but the metal are used. Also in the periodicity structure which consists of these thin films, since the characteristic value equation to an s-polarized light differs from the characteristic value equation to a p-polarized light originally, as for the maximum solution (an effective refractive index is determined by this maximum solution) obtained from each characteristic value equation, differing is common. From this, a thin film material will not be involved how, but birefringence nature will always exist in the periodicity structure, and the effective refractive index will have a line breadth dependency.

[0034] Furthermore, in the old example of a calculation, the diffraction grating with the cross-section configuration of a rectangle which is shown in drawing 1 is assumed. However, in the periodicity structure created using semiconductor lithography technique, it is rare to have the cross-section configuration of such a rectangle. Under such status, an effective refractive index cannot be expressed in (2 a) and the simple type like a formula (2b). Even if it is in such a case, when periodicity is in structure, a constitutive-property birefringence will surely exist, and the effective refractive index will have a line breadth dependency. From these arguments, the material of the periodicity structure and a cross-section configuration are not involved how, but by applying the polarization analysis described here shows that line breadth measurement is attained.

[0035]

[Effect of the Invention] Since actual measurement can moreover be performed in the atmospheric air, without destroying a sample once a calibration curve is made although the work which creates the calibration curve which connects various measurands and line breadth as a pre-setup of measurement is needed as mentioned above according to the line breadth measuring device and technique by this invention, the time of the line breadth measurement which is the credit of time and is required will be shortened sharply.

---

[Translation done.]

\* NOTICES \*

Japan Patent Office is not responsible for any  
damages caused by the use of this translation.

1. This document has been translated by computer. So the translation may not reflect the original precisely.
2. \*\*\*\* shows the word which can not be translated.
3. In the drawings, any words are not translated.

---

## DESCRIPTION OF DRAWINGS

---

[Brief Description of the Drawings]

[Drawing 1] Drawing of longitudinal section showing a line and a space pattern

[Drawing 2] Explanatory drawing showing the dependency over the duty ratio and wavelength of an effective-refractive-index difference

[Drawing 3] The cross section showing a thin film equivalent to a line and a space pattern

[Drawing 4] The block diagram showing the line breadth measuring device by the 1st example

[Drawing 5] The block diagram showing another mode of the 1st example

[Drawing 6] Inside [ of the drawing 4 and the drawing 5 ], a-a line, - f-f line view view

[Drawing 7] Drawing showing the dependency over the duty ratio of the polarization property of the reflected light from a line and a space pattern

[Drawing 8] Drawing showing the dependency over the duty ratio of the azimuth of the quenching shaft of the analyzer in the quenching status

[Drawing 9] Drawing showing the dependency over the duty ratio of the azimuth of the phase leading shaft of 1/4 wavelength plate in the quenching status

[Drawing 10] Drawing showing the dependency over the duty ratio of the azimuth of the transparency shaft of the analyzer in the status that the amount of transmitted lights serves as the maximum

[Drawing 11] The block diagram showing the line breadth measuring device by the 5th example

[Description of Notations]

K -- Light source P -- Polarizer

Px -- Transparency shaft B -- Beam splitter

U1 -- Incident light S -- A line and space pattern

U2 -- Reflected light Q -- 1/4 wavelength plate

Qx -- Phase leading shaft A -- Analyzer

Ax -- Transparency shaft D -- Light sensitive cell

H -- Line rectangular cross flat surface

---

[Translation done.]